Chapter 4
A Numerical Decoupling of a Wing Together with Two Nonlinear Radius-pylons, from the Technical Division's Substructuring Four-unit Frame Structure

A. Linderholt, B. Moldenhauer and D. Roettgen

Abstract To understand the structural dynamics of a complex mechanical assembly, it is often advantageous to study the dynamics of the individual components within the system. This has been utilized in numerical models for decades. An alternative is to represent the dynamics of these substructures using test data. Combining models based on vibrational test data with analytical/numerical models is known as experimental dynamic substructuring.

The Society of Experimental Mechanics' (SEM's) Technical Division on Dynamic Substructuring recognized a need for a geometrically simple yet conceptually challenging benchmark structure. A four-unit frame structure was designed to form its base. The substructuring collaboration was initially focused on linear substructuring but recent developments have led to an interesting nonlinear challenge problem.

Joints between substructures often cause nonlinear behavior in built-up systems; typical underlying physics including dry friction, varying contact areas, and other tribomechadynamic phenomena. Other causes are material nonlinearities, large deformation and contact in gaps/clearances. To include well-defined nonlinearities in the benchmark structure, the team from Sandia National Laboratories designed and manufactured a set of nonlinear subcomponents that serve as baseline examples. The design utilizes the four-unit frame as a basis and introduces wings with midspan lap joints as well as underwing pylons. The two pylon designs, the Gap Pylon (GP) and the Radius Pylon (RP), differ in the shape of the mounting blocks. The RP contains a smoothly varying contact with a metal strip while the GP features an abrupt change in the contact.

This study utilizes the four-unit Frame and rectangular jointed wing with attached RPs. Experimental dynamic substructuring is used to form a representation of the isolated nonlinear dynamics of the wing assembly by decoupling the dynamics of the Frame subsystem from the full structure. This process is completed at a range of excitation levels to characterize the nonlinear dynamics of the wing with two pylons as a function of response level. To avoid nonlinearities other than the one introduced by the RP, washers are inserted between the fuselage and the wing, between the wing parts in the lap joints, and between the wing and the upper pylon part. This work seeks to extend the boundaries of what is achievable with dynamic substructuring and demonstrate the process on a challenging use case.

Keywords Substructuring · Benchmark · Nonlinear · Decoupling

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Introduction

The Society of Experimental Mechanics' (SEM's) Technical Division on Dynamic Substructuring has established a challenging yet practical benchmark structure for experimental-analytical substructuring exercises. A team with members from many research institutes set out from several desirable properties and a unit-frame structure was designed to form the base. The benchmark structure is built up by a frame and different kinds of plates. Together, they can represent structures from a variety of fields; automotive chassis, wing-fuselage structure, and building floors are examples of assemblies that would be possible to represent by the benchmark structure [1]. The frame is made as a one-piece structure consisting of four square units with 10/32 threaded inserts that can be used to attach other components. Additional 10/32 tapped holes are included on the side of the frame to mount impedance heads or force transducers.

Structural joints commonly cause nonlinear behavior due to their inherent physics such as frictional slip and varying contact areas. Understanding these nonlinear phenomena are a significant and increasingly important challenge when attempting to identify and model the dynamic characteristics of complex structural assemblies such as aircraft. To initiate this challenge, the team from Sandia National Laboratories designed and manufactured a set of nonlinear subcomponents for the four-unit frame that serve as a baseline example of what hardware could be utilized [2]. To facilitate collaboration and involvement, the technical drawings and CAD models of these subcomponents are freely available to any interested researchers on the Dynamic Substructuring Wiki [3]. This design is largely based on that used in [4], and originally proposed in [5]. The pylons are effectively pendulums in which a thin strip of metal is clamped at the top via two mounting blocks and has two masses adhered to the bottom. There are two designs that differ only in how the metal strip contacts the top mounting blocks. The two options, deemed the Gap Pylon and Radius Pylon, feature either an abrupt transition or a smooth curvature, respectively, between where the metal strip is clamped and the base of the mounting blocks.

The main objectives in this study are to measure the nonlinear characteristics of the four-unit frame together with the jointed wing and pylons and to conduct a numerical decoupling exercise. A major part in this work has been to devise a test setup enabling accurate measurements of the frame, wing and pylons. Another part has been to measure the dynamics of the structure at different excitation levels. During the presentation at the conference, results will be shown to demonstrate how the substructuring decoupling performed at different amplitude levels of the benchmark system.

Testing

The test structure offers many possible causes of nonlinear dynamics. It also enables many ways to define the substructures. Additionally, test setups, tests and decoupling can each be performed in many ways. Here, the jointed wing with two radius pylons constitutes the nonlinear substructure and the four-unit frame fuselage constitutes the substructure to be subtracted from the assembly. The decoupling operation is performed using virtual points where the two subsystems are assembled and results in linearized eigenmodes for different excitation levels.

To avoid nonlinearities other than the one in the pylon, washers were included between the fuselage and the wing, between the wing parts in the lap joints, and between the wing and the upper pylon part. The test structure was suspended by fish lines in a "free-free" condition. The excitation for the assembly was provided by a Modal Shop Modal Shaker Model 2025 attached to the corner of the frame and a chirp signal was used as the source definition. A PCB 288D01 impedance head was used to estimate the drive point accelerance. Finally, a Polytec 3D Scanning Laser Doppler Vibrometer (SLDV) was used for the motion measurements. This first part in the study, i.e. establishing a test setup, at Linnaeus University (LNU), that can be used to conduct accurate vibrational tests on this nonlinear structure, resulted in the test setup shown in Figure 1. Additional testing will be performed at Sandia National Laboratories to test a nominally identical nonlinear benchmark system to gauge the similarity and repeatability of the assembly and setup.

Modal Analysis

First, a low excitation level of about 1 Newton was utilized to generate a baseline linear response. Some of the lowest elastic eigenmodes are described in Table 1 and shown in Figure 2. These modes will be monitored at increasing excitation levels regarding their observable nonlinear behavior. For each excitation level, decoupling of the fuselage from the wing and pylons will be conducted using experimental substructuring. Tracking the frequency and dampingchange in the modes will be essential for understanding the performance of dynamic substructuring techniques.

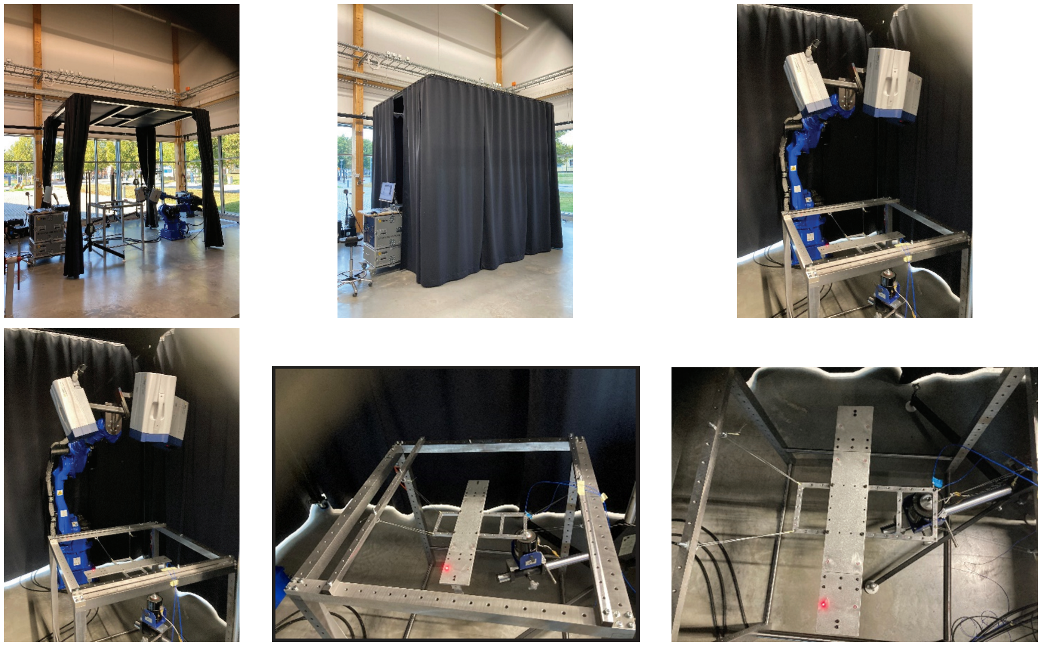

Fig. 1 The test setup at LNU of the fuselage and the wing together with two Radius Pylons. A modal shaker was used for excitation and a Polytec 3D Scanning Laser Doppler Vibrometer was used for non-contact measurements.

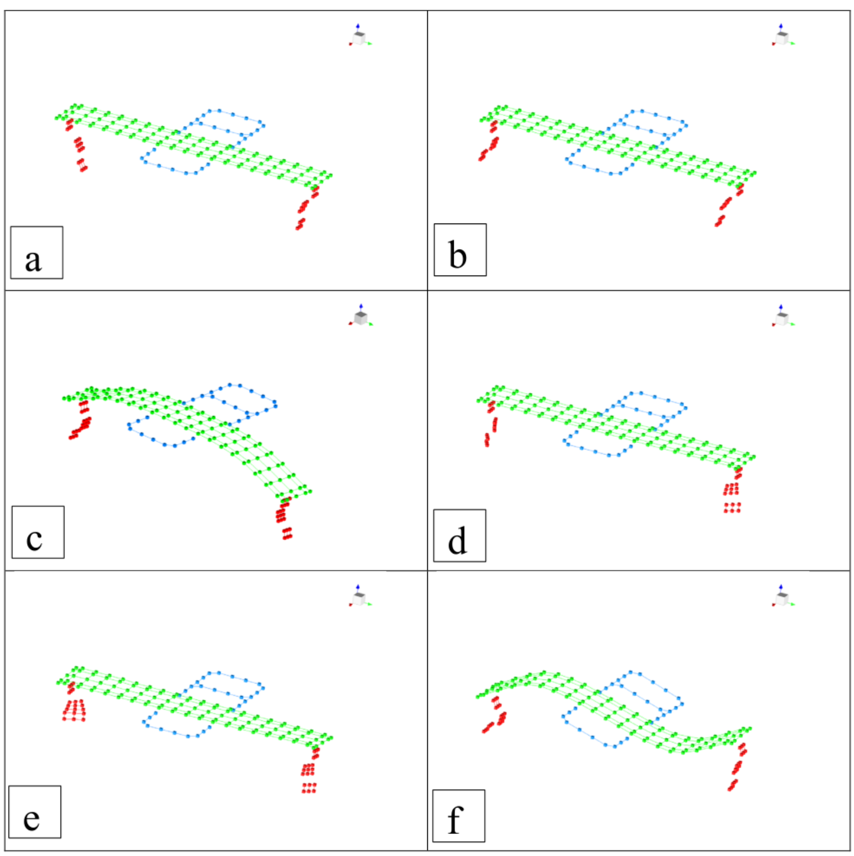

Fig. 2 Six elastic mode shapes at a low excitation level. a) symmetric bending of the pylons, b) anti-symmetric bending of the pylons, c) first symmetric wing bending, d) symmetric torsion of the pylons, e) anti- symmetric torsion of the pylons, f) first anti-symmetric wing bending.

Table 1 Six elastic modes estimated from measurements with a low excitation level.

Natural Frequency [Hz]	Mode Shape Description
14.3	symmetric bending of the pylons
14.9	anti-symmetric bending of the pylons
49.9	first symmetric wing bending
96.3	symmetric torsion of the pylons
97.0	anti-symmetric torsion of the pylons
109.4	first anti-symmetric wing bending

Conclusion

The four-unit frame together with the lap-jointed wing and two Radius Pylons are used in a test campaign in which chirp signals supplied to a shaker were used to excite the structure. Linearized eigenmodes were extracted for increasing excitation levels. Some of these modes are monitored as a function of excitation level. A main part of the work was to achieve a test set-up enabling accurate vibration tests of the structure. From the first tests, it can be concluded that the structure has a high modal density and should provide an enlightening challenge problem for dynamic substructuring decoupling.

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